A new ground test for determining the resolution of pushbroom sensors

Michael J. Jenquin

Naval Air Warfare Center Aircraft Division
Patuxent River, Maryland 20570-5304

ABSTRACT

A "pushbroom" sensor is an airborne imaging system which takes a series of one dimensional samples orthogonal to the aircraft line of flight with the second dimension constructed by the forward motion of the platform. With the advent of these highly sophisticated pushbroom reconnaissance sensors, system testing organizations are required to perform a detailed assessment of sensor performance. While in the past, systems have traditionally been tested using static or scrolling stimulation, such techniques have proven to yield only limited data.

The Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland has developed a ground test capability which supplies highly diverse and repeatable data and which provides a solid statistical base for the determination of system resolution. Working closely with the 3246 TW/DOR, Eglin Air Force Base, Florida, the exploitable nature of these data has been verified.

This paper presents the data as actually taken from ground tests of a pushbroom sensor performed at Eglin Air Force Base and illustrates the methods and techniques employed to analyze and evaluate the resulting imagery.

1. BACKGROUND

Last year the Naval Air Warfare Center Aircraft Division, Patuxent River Maryland and Sverdrrup Technology, TEAS Group, Eglin Air Force Base, Florida presented a joint paper outlining the developmental test and evaluation plans for the Advanced Tactical Airborne Reconnaissance System (ATARS). In that article a new ground test method by which a system such as ATARS could be evaluated was described. That test involved a spinning target which would stimulate the sensor in such a way as to introduce temporal parameters into the evaluation of the sensors. The results from the validation test of this apparatus and the mathematical model since derived to explain those data will now be presented.

For those interested, the previous paper describes in detail the spinning target apparatus. For those not so inclined, let it suffice to say that by spinning a standard resolution target in the object plane of a collimator aligned with the sensor under test, some interesting data can be gleaned.

2. VALIDATION OF TEST RESULTS

After the design and fabrication of the prototype spinning target apparatus, the test set was shipped to Eglin Air Force Base, Florida. On October 10, 1991 a ground test was performed on the ATARS Low Altitude Electro-Optical (LAEO) sensor. The experiment was not as controlled as it might have been due to lack of preparation time and the need for this test to have as little impact on test program as possible. The imagery as seen from the cockpit display was not what we had been expecting, but the proof of this test approach would be in the full resolution imagery which could only be extracted from the digital tape recorders which are part of the ATARS suite. The full resolution imagery showed that while a pattern was there, it too was not quite what we had expected. Proceeding from the assumption that perhaps there might have been an alignment problem during the test, we derived the following relationship.

3. MATHEMATICAL MODEL

Figure 1 shows a target at some point in a cycle of spinning about its centroid. By approaching the problem of what a line scanning sensor would see by vector analysis, with the x and y axes in the convectional orientation, we find the following:

Let C be the centroid of the target and A be the width of a bar of the target.

Let **R** be the vector from C to an edge of the target via the shortest path i.e. R is orthogonal to the edge.

Let **D** be the alignment error between the plane of scan and that of the plane parallel to the plane of scan and passing through the centroid of the target.

Let **S** represent the vector from the point laterally aligned with the target and an edge of the target.

And let **L** be a vector running along that edge to the tip of vector R. So L just completes the loop so that we can say:

$$R = D + S + L$$

or:

$$L = R - D - S$$

Now, if we define an angle, θ which is the angle subtended by R and the line through the centroid and in the plane parallel to the plane of scan, we can describe these four vectors as follows:

$$R = R[\cos(\theta)\mathbf{x} + \sin(\theta)\mathbf{y}]$$

$$D = D\mathbf{y}$$

$$S = S\mathbf{x}$$

and:

$$L = L[\sin(\theta)\mathbf{x} - \cos(\theta)\mathbf{y}]$$

but:

$$L = [R\cos(\theta) - S]\mathbf{x} + [R\sin(\theta) - D]\mathbf{y}$$

By setting these two expressions for **L** equal to each other (which they obviously are) and breaking down the vector into its scaler components we can solve for S which is what we really want anyway. Doing this we find that:

$$S = R/\cos(\theta) - D\tan(\theta)$$

From this we see that if there is no alignment error (D = 0) we have the $R/\cos(\theta)$ expression that we had expected from last year's paper. But if there was an alignment error we would get something different. Now the question is; if we assumed some value for the alignment error, could we reproduce the skewed star-pattern which we found in the validation test?

Figure 2 shows a comparison of the mathematical model with the imagery from that test. From this evidence we can feel confident that our model is valid. But, perhaps we can go further; we could turn this discovery to our advantage. Let's start with what we know. We know that pushbroom sensors such as ATARS assume that it is imaging the earth below, which is by and large a static field. At this point we have a problem. The edges of the target are only frozen in time at certain points in the rotation. These points are also dependent upon the alignment error as the sensor scans the target. We must find a way to determine where in the rotation cycle we expect a given edge to be frozen in time in order to emulate the terrain below in a valid way. Taking the partial derivative of the function we derived, we find that for a given edge and alignment error the angle (call it θ_F) can be described by:

$$\theta_F = \sin^{-1}[-D/R]$$

Now we have the capability to describe the angle at which our data is valid. Not only that, but we can describe the resolution of the sensor as a function of the angle between the plane of scan and that of a given edge. This in turn gives us the capability to describe the resolution of pushbroom sensors in a totally new way using statistical methods.

3.1 Step Response

The resolution of a sensor is an arbitrary and subjective measurement when the system is part of a human-in-the-loop test. Fortunately, ATARS integration issues can be evaluated objectively by the following method: The true figure of merit for an Electro-Optical or Infrared imaging system is actually the sensor's ability to detect edges. For example, if a given pixel footprint were to fall on an area of an irradiance corresponding to a maximum value, i.e. 255 on an eight bit system, and the adjacent pixel footprint fell on an area corresponding to zero, and the system was ideal, the first pixel would register 255 and the second would register zero. If, however, the system were not ideal one might find that the first pixel would register 200 and the second 25. We might find that the latter pixel value represents the noise floor of the system or it could be that through imperfections in the system that it is a transition pixel and that the next pixel or the next several pixels are required to reach a minimum value. By counting the number of pixels needed to transition from an initial value to a final value the step response of the system can be defined.

One attractive feature of this approach is that the need to use several targets of various dimensions no longer exists. Also, since larger targets are being used, alignment problems become less critical. This is not to say that spatial phasing is no longer a problem. In order to overcome such difficulties many samples must be taken from which a statistical analysis can be performed.

SPINNING TARGET ALIGNMENT ERROR ANAYSIS

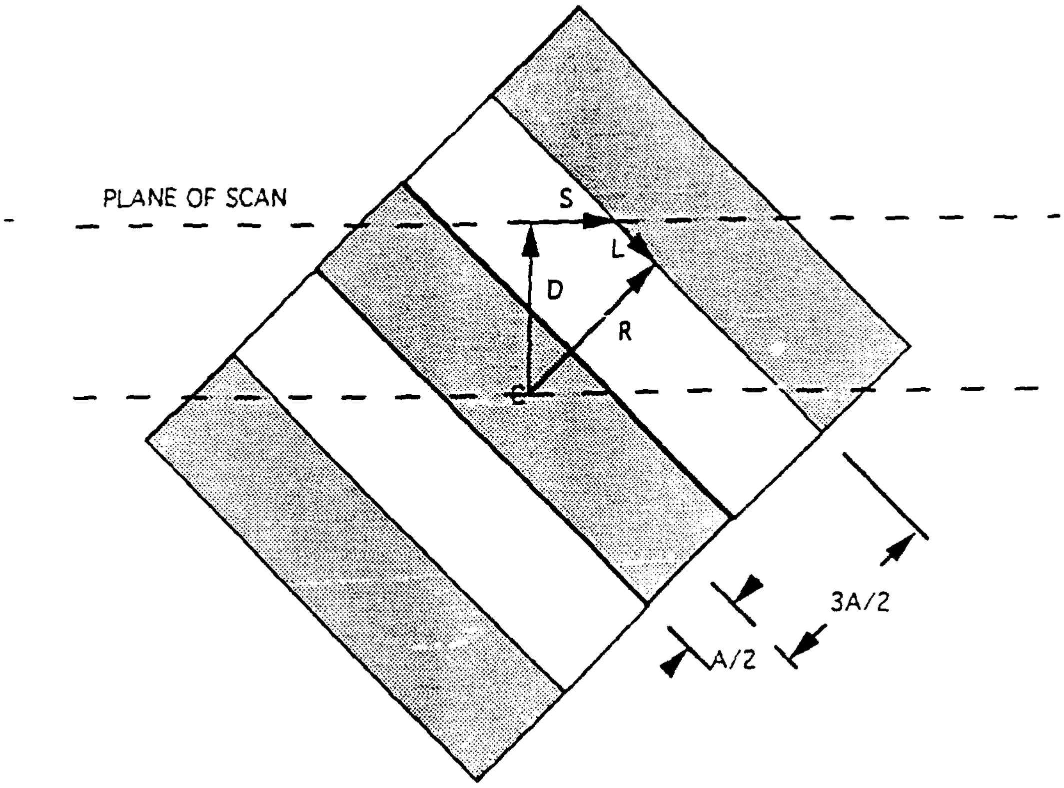
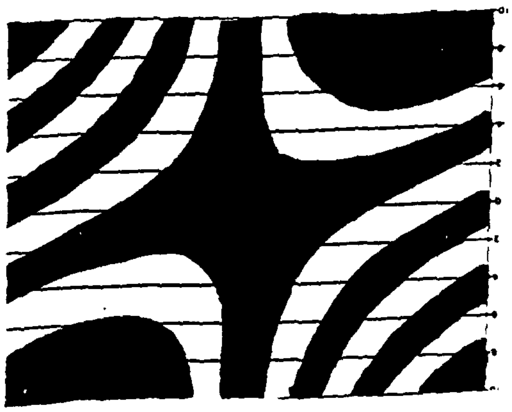
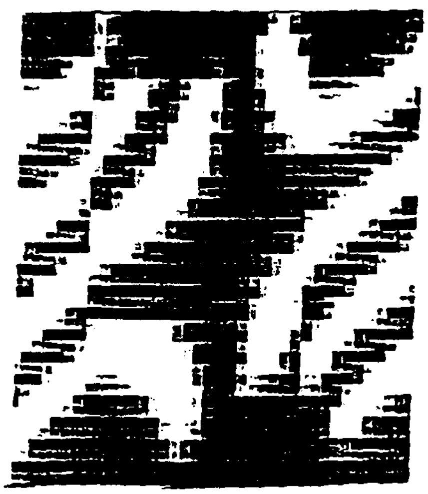


FIGURE 1



MATHEMATICAL MODEL



ACTUAL IMAGERY

FIGURE 2